PROGRESS REPORT

Contract N00014-95-C2088

RESEARCH IN LASERS, FELS, BEAMS, AND NEURAL NETWORKS AND THEIR APPLICATION TO FUSION, SPACE, AND LABORATORY PLASMAS

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Principal Investigator: V.L. Granatstein

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SUBJECT PAGE

COAXIAL HYBRID IRON WIGGLER FEL

Contact Persons: Victor Granatstein/J. M. Taccetti

PROGRESS REPORT:

The following is a report on the research performed at NRL on the CHI (Coaxial Hybrid Iron) wiggler free electron later experiment during the 1996-97 fiscal year.

Annular-Beam Electron Gun

The modifications on an existing SLAC klystron XK-5 electron gun, modified to emit an annular instead of a solid beam, have been completed. After receiving the modified cathode/heater/focus electrode assembly from Heatwave (cathode itself fabricated by Spectromat), it was aligned to the anode by way of an aligning tool fabricated at NRL.

Other modifications were also performed on the gun to improve its vacuum during operation. Pumping holes were added on the anode section and a pumping manifold, holding four eight-liter ion pumps, was fabricated at NRL (pumping was previously done from the back of the gun, which resulted in a poor pumping rate). A straight output section with an inner lining of copper was also fabricated at NRL and brazed to the gun in a dry-hydrogen furnace at Burle Ind. This output section connects the gun to the rest of the experiment via a ConFlat flange. The gun was connected to the gate valve and achieved a bakeout pressure of 5×10^{-19} Torr. It is presently ready to be inserted into the experiment and activated. The gun is expected to deliver a 10 A beam at 100 kV. An aluminum mount to hold the gun in the oil tank was also designed and fabricated. This mount holds the gun rigidly to the oil tank after aligning to the experiment and also has a system of o-rings to keep the oil from leaking out. The trim coils for focusing of the beam (along with their cooling system) have also been installed and tested.

CHI Wiggler

The CHI wiggler design has been completed, the wiggler has been fabricated, and its fields measured and compared to theoryThe wiggler entry taper region was designed using POISSON. This was necessary in order for the beam to enter the interaction region. Axial fields existing in the CHI wiggler would 'kick' the beam out toward the walls if the transverse motion is imparted to the beam non-adiabatically. Once this was achieved, a realizable experimental design was arrived at. This design was kept simple and flexible in case that any changes are necessary. The outside wiggler pieces are indexed on the inside diameter of an outer shell, which was honed to tight tolerances. The waveguide fits inside of these and also serves as the vacuum envelope. The inside wiggler parts are enclosed an inner waveguide and are therefore also outside of the vacuum envelope. All the wiggler parts were fabricated at AccuTool. Once received, the wiggler parts were carefully measured and from these the best were selected. The wiggler was then assembled, insuring that the inside and outside wiggler sections were of the same length, to avoid them from becoming out of phase with each other. The solenoidal field is very intimately coupled to the CHI fields, and therefore a careful measurement was performed, especially to find the correct position of its magnetic axis with respect to its physical axis. A simple system was devised and fabricated to position the wiggler inside the bore of the solenoid at the magnetic axis. Measurements of the gap-center fields of the wiggler in the magnetic axis were obtained, and they agree very well with expected fields. The supports for the inner rods were designed and fabricated. With help from Dr. Calame, it was theoretically confirmed that they would survive beam interception.

RF

Extensive work was performed towards the completion of the input and output rf couplers. The input coupler actually includes two sections: a four-way power splitter and an outer coax to inner coax coupler. The four-way power splitter was cold tested on a recently acquired vector network analyzer to test that the four outputs are in phase with each other. Rf transmission to each of the four outputs was found to be (independent measurements) 21%, 22%, 19%, and 20% at the center frequency of 35 GHz. The phase differences between the input and each of these outputs

were measured to be: 92.4, 98.8, 98.6, 93.2 degrees, respectively. This still falls short of the 25% transmission and in-phase operation of each of the four outputs, but it is believed the difference may be due to reflections in a part of the cold-test output section which shorts out the mode currents. The operation of the brazed power splitter/output coupler combination will be cold-tested shortly. The input coupler is in the process of being brazed at the University of Maryland. The output coupler was made similarly to the input, except that: a) it couples out only part of the power, about 15%, to avoid breakdown), and b) it does not recombine the power but allows testing of the power at each port separately. The output coupler then will allow a diagnosis of the output power vs. frequency. The rest of the rf travels down the tube to a calorimeter and provides a measurement of the total amplified rf power. Towards learning more about the brazing of the input coupler, multiple brazing tests had to be performed (both for the brazing of the power splitter and the taper section in the couplers). An anechoic chamber was also designed, for use from 35 to 94 GHz, though in the end it will not be used in the experiment, due to the unavailability of funds to fabricate it in the allotted time.

List of Publications for the 1996-97 Fiscal Year:

Proceedings:

``Operation of a Ka-Band CHI Wiggler Ubitron Amplifier," J.M. Taccetti, R.H. Jackson, H.P. Freund, D.E. Pershing, V.L. Granatstein, Digest of the 22nd International Conference on Infrared and Millimeter Waves, Wintergreen, Virginia, July 20-25, 1997.

``Progress on a Ka-Band CHI Wiggler Ubitron Amplifier," J.M. Taccetti, R.H. Jackson, H.P. Freund, D.E. Pershing, V.L. Granatstein, 1997 Vacuum Electronics Annual Review, San Diego, California, May 19-22, 1997.

Contributed Papers:

``Operation of a Ka-Band CHI Wiggler Ubitron Amplifier," J.M. Taccetti, R.H. Jackson, H.P. Freund, D.E. Pershing, V.L. Granatstein, 22nd International Conference on Infrared and Millimeter Waves, Wintergreen, Virginia, July 20-25, 1997.

``Progress on a Ka-Band CHI Wiggler Ubitron Amplifier," J.M. Taccetti, R.H. Jackson, H.P. Freund, D.E. Pershing, V.L. Granatstein, 24th IEEE International Conference on Plasma Science, San Diego, California, May 19-22, 1997.

FIELD EMISSION ARRAY TWYSTRODE

Contact Persons: Victor Granatstein/Morag Garven

PROGRESS REPORT:

Phase Noise of RF sources

Phase stability of RF sources is of interest for many applications including radar, communications and particle accelerators. The spurious response of any amplifier tube used in a radar system is of importance; measurement of this response is critical for power supply specification as well as for determination of system design tradeoffs. At the Naval Research Laboratory, a high average power gyroklystron amplifier is currently being developed as the driver for a W-band radar [1]. As a result, an investigation of phase noise in mm-wave amplifiers has recently been initiated. An experimental study of phase stability in a four-cavity, 94GHz gyroklystron has been completed. This involved measuring phase stability as a function of beam voltage, magnetic field and output power of the gyroklystron. A cathode voltage pushing factor of 40.6 °/kV was measured. This corresponds to a spurious response of -63 dBc for a 1 V rms ripple on the cathode voltage supply, which is in accordance with the W-band radar design specifications. The experimental data was found to be in good agreement with theoretical predictions, which were calculated using MAGYKL [2].Noise figure measurements and different techniques for the acquisition of phase and amplitude noise data are currently being studied.

In addition to the W-band gyroklystron program, a successful Ka-band, two cavity experiment was recently reported [3]. Noise investigations and measurements using this gyroklystron are also underway.

Extrinsic Noise Studies in Gyro-amplifiers

A theoretical study of the effect of fluctuations in gyrotron extrinsic operating parameters such as beam voltage, beam current and magnetic fields has previously been performed for free-running and phase locked gyro-oscillators [4,5]. It was shown that this extrinsic noise causes the broadening of the radiation linewidth in gyrodevices. A similar numerical study of this effect in a four cavity, 94GHz gyroklystron amplifier has been performed. This involved formulating and evaluating the theory for gyro-amplifiers. Results have been obtained for the NRL W-band gyroklystron and experimental corroboration of these results is planned.

Gyroklystron Input Coupler Theory

A simple analytical theory of input couplers for gyroklystron amplifiers has been formulated and evaluated. In the NRL W-band gyroklystron experiment, the input coupler is designed using a modern Maxwell's equation solver, HFSS [6]. The purpose of this work was to develop an approximate but much simpler formulation for the coupling problem. For this case, the dipole approximation was used for the coupling holes.

The dipole theory was compared to HFSS for zero thickness walls. The theory was programmed using Matlab and a full frequency response of the input coupler takes a few minutes to calculate and display using a PC. Therefore, it is a means to become oriented in a wide, multi-dimensional parameter space. Both the formulation and the Matlab results have given simple analytic insights which can help to interpret HFSS simulations and minimise HFSS run time. In regions where the dipole theory is valid, it gives good qualitative agreement. Furthermore, the dipole theory is generic, and can be applied to different coupler designs. There are other future improvements which can be made to the dipole theory, including accounting for wall thickness and using waveguide T relations where appropriate.

Twystrode Using Field Emitter Arrays (FEAs)

The investigation of a new class of microwave power amplifiers based on field emitter array (FEA) technology is currently underway at the Naval Research Laboratory. Advantages of using FEAs in microwave amplifiers include instant activation, higher transconductance and higher current densities than gridded thermionic cathodes resulting in higher performance microwave power tubes. A twystrode employing an FEA cathode is being designed to operate at 10 GHz with 50 W output power and 10 dB gain. FEAs will be used to generate an electron beam of up to 40 mA at 2.5 kV with a magnetic field of 5 to 6 kG. Prior to the operation of the FEA cathode in the twystrode, a series of experiments has been undertaken to maximize the beam power and beam transport from the FEA cathode. Emission currents were found to be largely unaffected by the operating mode - either DC or pulsed. Currents on the order of 2mA per quadrant have been measured, indicating that total currents in the range of 8-10 mA should be obtainable as required for an initial demonstration of an FEA twystrode.

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G. S. Nusinovich, M. Garven, O. Dumbrajs and B. G. Danly, "Theory of Extrinsic Noise in Multicavity Gyroklystrons," 22^{nd} IR&MM waves Conf., Wintergreen, 1997.

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SIMULATION OF GYRO-TWT AMPLIFIERS

Contact Person: Victor Granatstein/Simon Cooke

PROGRESS REPORT:

Eigenmodes of low-Q cavities

A recently published numerical method (Jacobi-Davidson [1]) has been adapted to determine selected microwave cavity eigenmodes of 2- and 3-dimensional structures containing dielectric materials. The method solves for the eigensolutions of a large, sparse linear system of equations obtained using a finite-integration discretisation method, with approx. 10^6 unknowns. In particular, the applicability of the method was extended to model systems containing materials such as some ceramics, which may be very strongly absorbing at microwave frequencies. Such systems lead in the numerical solution to non-Hermitian matrices with complex eigenvalues and linearly dependent eigenvectors, and have in the past proved problematical to existing numerical methods. Difficulties were identified as being due to breaking of the usual orthogonality relation of eigenvectors for such systems, and were resolved by deriving a complex-symmetric form of the operator, for which a bi-orthogonality relationship exists. For this form of operator, corresponding left- and right-eigenvectors are complex conjugate, and therefore a solution using complex-conjugate eigenvector subspaces was implemented. The new method has been successfully applied to large electromagnetic problems with very strongly absorbing materials.

Gyroklystron cavity modelling

A number of components for the three and four cavity gyroklystron amplifier experiments at the Naval Research Laboratory have been modelled using numerical codes which have been developed for field calculations in waveguides and cavities containing arbitrary distributions of (possibly lossy) materials in a cylindrical or 2D-cartesian geometry. The reflected microwave signal from a calorimeter diagnostic was evaluated as a function of frequency and compared to ray-tracing and HFSS simulations, and experimental data. Ceramic loaded cavities used in the NRL gyroklystron amplifier experiments were modelled and compared successfully with HFSS simulation results, providing a fast tool for essentially two-dimensional cylindrical or planar circuit geometries. The thermal distribution arising from heating by absorption of microwave energy in the ceramic materials was also assessed using an adaptive finite element package.

Gyro-TWT amplifier using Spiral waveguide

Recently, a novel electrodynamic system has been proposed to realise high amplification and a broad frequency band in a cyclotron-resonance maser amplifier at millimeter and microwave frequencies [2]. A cylindrical waveguide with a helically grooved wall selectively couples an electromagnetic mode at a frequency close to cutoff to the forward travelling wave of a lower mode, resulting in a travelling eigenwave with positive group velocity and approximately zero axial wavenumber. For a travelling wave amplifier, such a dispersion characteristic may permit operation with increased bandwidth and reduced

sensitivity to beam axial velocity spread by operating close to the point $k_z = 0$ for which there is minimal Doppler shift.

The linear and non-linear theory for cyclotron interaction with the electromagnetic modes of a spiral-corrugated waveguide have been developed, and a numerical investigation performed of the coupled dispersion characteristics, oscillation threshold and gain spectrum of a gyro-TWT amplifier using resonantly coupled modes, optimized for suppression of parasitic oscillations. The wall corrugation has been shown to increase threshold currents for the onset of oscillation, by breaking the waveguide symmetry. For waves close to the cut-off frequency, associated with unwanted gyrotron oscillations with low starting current, coupling of power to a travelling wave mode was shown to raise the threshold current significantly. Instantaneous bandwidth of the device was found to be greater than for an equivalent amplifier circuit in smooth cylindrical waveguide, and was found to be much less sensitive to a spread of particle velocities in the electron beam.

Noise calculation

Amplification of noise by a cyclotron electron beam may induce energy spread in the particles sufficient to degrade the performance of gyrotron oscillators and gyro-amplifiers A calculation of the noise amplification spectrum due to excitation of plasma modes of an electron beam in a magnetic field [3] has been performed for the electron beam of the Naval Research Laboratory 94GHz gyroklystron amplifier experiment. The calculation was performed using beam parameter values obtained from a particle code for electron velocity, energy and including the spreads of the distribution. Noise amplification was evaluated as a function of electron beam current for this experiment.

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EXCIMER LASER TECHNOLOGY

Contact Person: J. Goldhar

PROGRESS REPORT:

Plasma electrode Pockels' cell with 1cm size aperture and 4:1 aspect ratio has been demonstrated to operate at subnanosecond rise times and contrast ratio's orders of magnitude better than that of commercially available devices. The emphasis of the research during this year was on improvement of plasma uniformity, reproducibility and streamlining of the design for cleaner electrical pulse propagation through the cell. Careful study of operating parameters showed that if the purity of the gain the cell was sufficiently high, and electrodes properly conditioned after exposure to air, the erratic plasma behavior observed previously could be eliminated. However, some intermitted problems due occasional breakdown to the metal walls of the cell continued to occur. These problems were eliminated if the pressure was increased to 100 Torr, however at such high pressure plasma reproducibility was harder to maintain. The solution was a complete redesign of the cell. New models have much larger volume, to minimize the contamination problems from out gassing and micro-leaks, and insulating (mostly glass and mykor) cell body. Measurements of relationship between the electrical characteristics of plasma producing current and the transmission of the short duration switching pulse was investigated. Although the results showed significant and not fully explainable variations from day to day, which could have been due to conditioning of the electrode's surfaces, it was possible to demonstrate several times that good transmission (>85%) of fast pulse was obtainable with uniform and reproducible plasma. In addition to the work on the plasma electrodes we continued to develop subpicosecond KrF capabilities. We have in the LAMOSE laboratory a high power Ti:Sapphire laser system.

We succeeded in tripling the frequency of this laser and are getting ready to amplify the seed in the commercial KrF discharge laser.This facility should provide us with a good source of high peak power UV pulses for nonlinear optical studies.

LASER PLASMA INTERACTIONS

Contact Person : P. N. Guzdar

1. Multi-pump Driven Stimulated Brillouin Scattering in Homogeneous Plasmas

We have extended the investigation of our multi-beam studies to Brillouin Scattering. The first configuration referred to as the Symmetric Plasma Mode, (based on the earlier work by Dubois, Bezzerides and Rose[1]), is one in which a single acoustic wave with wave-vector along the axis of symmetry of the incident beams couples to the multi-beam pump, with multiple scattered waves which satisfy the wave-vector and frequency matching conditions. We have established that for the intensity in each of the NIKE beams, (2-3X10^{12} Watts/cm^2) the angle between each of the beams is large enough so as to be below the threshold of this collective scattering process. The condition that each of the beams act independently for this so as not to excite this collective mode is

A second collective mode that we have examined is the symmetric light mode, where a single back-scattered light wave along the axis of symmetry of the laser beams, couple to multiple acoustic waves, which satisfy the wave-matching and frequency matching conditions. We find that the threshold for this process is significantly lower than that of the symmetric acoustic wave. This is because the condition of each of the beams to act independently depends on the frequency difference of the acoustic waves with different wave vectors dictated by the k matching conditions between the symmetric light mode and the multiple pump beam. As a consequence this mode has a reasonable chance (for I ~ 5x10^3 to 10^{14}) of being excited especially due to statistical enhancements caused by the interference of the multiple beamlets. We have found that the finite angle between the beamlets has a tendency to mitigate the statistical enhancements and the threshold is basically that of putting all the power in one beam.

2. Nonlinear Raman in an inhomogeneous, multi-ion plasma

Recent observations of Raman scattering in Hohlraum as well as gas bag plasmas on the NOVA facility has sparked a lot of interest because of the surprising results. The experiments were aimed at increasing the Ion-Landau damping of ions keeping the electron density, the ratio of the in and electron temperature and Z (charge) constant. What was found was that the Raman instability increases (from 5 to 15 %) as the ratio ion ratio of ν_{ia}/ω_{ia} was increased. Furthermore it was found that there is an anti-correlation between Raman and Brillouin Scattering. Whenever Raman is high Brillouin Scattering, was observed to be suppressed and vice-versa. We have developed a 1D nonlinear code to study Raman in an inhomogeneous plasma. The low frequency ion response is derived for a multi-ion plasma which controls the nonlinear saturation of the instability. Furthermore by changing the gas mix the $Z_{eff} = \Sigma n_i Z_i^2/n_e$ of the plasma is altered. The collisional damping of the plasma wave is strongly affected by the Z_{eff} of the plasma especially in the nonlinear phase. Thus we are currently studying the role of Z_{eff} as well as the multi-ion low frequency response on the saturation of the Raman instability in an inhomogeneous plasma. This is a very different approach compare to work by other groups who attribute the increase the Raman as ν_{ia}/ω_{ia}

was increased due to the suppression of the Langmuir Decay Instability, which is believed to control the saturation level of the Raman backscatter.

PRESENTATIONS AT CONFERENCES

1. "Multi-Beam Pump driven parametric instabilities" 27^{th} Annual Anomalous Absorption Conference" 1-5^{th} June 1997, Vancouver, BC

2. "Nonlinear Raman in a multi-ion Plasma", APS Meeting of the DPP, 17^{th}-21^{th} Nov 1997 at Pittsburgh, PA.

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HIGH-ALTITUDE LIGHTNING

Contact Person: Dennis Papadopoulos

PROGRESS REPORT:

1. High Altitude Lightning

A code to model streamers induced by high altitude lightning was developed. The code was coupled to the fractal antenna code. Preliminary results indicate that streamer development can account for the optical observations.

2. Ionospheric Modifications

A draft of the report on "Research Opportunities and Applications using the HAARP Facility" is on the final stage of preparation. It is expected that it will be ready by December 1997.